

**United States Patent Application
in the Name of**

Shivakumar Seetharaman

and

Georgios S. Asmanis

for

TRANSIMPEDANCE AMPLIFIER

Prepared by: Paul G. Nagy
Patent Attorney

Docket No. P16569

intel®

Intel Corporation
1960 E. Grand Avenue, Suite 150
El Segundo, CA 90245
Phone: (310) 252-7621
Facsimile: (310) 640-7133

"Express Mail" Label Number: **EV 324059865 US**

TRANSIMPEDANCE AMPLIFIER

BACKGROUND

The subject matter disclosed herein relates to U.S. Patent Appl. Ser. Nos.
5 10/074,099 and 10/074,397, filed on February 11, 2002, and U.S. Patent Appl. Ser. Nos.
10/325,048; 10/325,026; 10/324,999 and 10/324,983 filed on December 20, 2002.

1. Field:

The subject matter disclosed herein relates to data communication systems. In
particular, embodiments disclosed herein relate to processing data received from an
10 optical transmission medium.

2. Information:

Optical communication networks have been implemented to enable increased data
rates in links providing point to point communication. For example, optical
communication links are typically implemented in Synchronous Optical
15 Network/Synchronous Digital Hierarchy (SONET/SDH) and 10 Gigabit Ethernet
systems. At a receiving end of such an optical communication link, a photodiode may
generate a current in response an optical signal received from an optical transmission
medium (e.g., fiber optical cabling). A transimpedance amplifier (TIA) typically
converts the current generated by the photodiode into a voltage signal that is then
20 processed. For example, the voltage signal may be processed by clock and data recovery
circuitry to recover data transmitted in the optical signal.

A TIA typically comprises a feedback circuit to remove a DC component of an
input signal. A low pass filter (LPF) typically receives an output signal from the TIA to
isolate the DC component. A DC removal circuit may then remove all or a portion of the

DC component from the input signal based upon the DC component isolated from the output signal.

An LPF in an electronic device typically comprises an off-chip capacitor that may be coupled to one or more circuit elements in the electronic device by an external circuit bonding pad. When coupled to the one or more circuit bonding pads, the capacitor may be coupled to the one or more circuit elements through one or more conductive portions formed in the electronic device (e.g., as part of a circuit layout for a semiconductor device). At high frequency operation, the conductive portions may introduce a parasitic impedance resulting from a parasitic resistance and/or a parasitic inductance.

The parasitic resistance of a conductive portion may be reduced by, for example, increasing the cross-sectional area or width of the conductive portion (i.e., with reference to the direction of current between the off-chip capacitor and circuit elements in the electronic device). For a given conductive material (e.g., copper) increasing the cross-sectional area or width may lower the parasitic resistance proportionally. Decreases in parasitic inductance may also result from increasing the cross-sectional area or width. However, at a given operating frequency and conductor cross-sectional area or width, saturation may prevent significant further decreases in parasitic inductance from further increases in cross-sectional area or width.

BRIEF DESCRIPTION OF THE FIGURES

Non-limiting and non-exhaustive embodiments of the present invention will be described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various figures unless otherwise specified.

5 Figure 1 shows a schematic diagram of a system to transmit data in and receive data from an optical transmission medium according to an embodiment of the present invention.

Figure 2 shows a schematic diagram of physical medium attachment (PMA) and physical medium dependent (PMD) sections of a data transmission system according to
10 an embodiment of the system shown in Figure 2.

Figure 3A shows a schematic diagram of a system to remove at least a portion of a DC signal component from an input signal according to an embodiment of the present invention.

Figure 3B shows a circuit layout of a conductive portion of a circuit to be coupled
15 to an off-chip capacitor according to an embodiment of the system shown in Figure 3A.

Figure 3C shows a schematic diagram of an amplifier coupled to a low pass filter according to an embodiment of the system shown in Figure 3A.

Figures 4A and 4B show schematic diagrams of a transimpedance amplifier (TIA) according to alternative embodiments of the PMD section shown in Figure 2.

20 Figure 5 shows a schematic diagram of a multistage amplifier according to an embodiment of a TIA shown in either Figure 4A or 4B.

Figure 6 shows a schematic diagram of a limiting amplifier (LIA) according to an embodiment of the PMD section shown in Figure 2.

DETAILED DESCRIPTION

Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrase “in one embodiment” or “an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in one or more embodiments.

A “photodiode” as referred to herein relates to a device that provides an output current in response to light energy collected on a surface. For example, a photodiode may provide an output current in response to charge collected at a photodiode gate. However, this is merely an example of a photodiode and embodiments of the present invention are not limited in this respect.

An “amplifier” as referred to herein relates to a device or circuit to convert an input signal to an amplified output signal. For example, an amplifier may provide an amplified output signal having a magnitude that is related to a magnitude of an input signal by an amplification gain. In another example, an amplifier may generate a voltage signal having a magnitude related by an amplification gain to a magnitude of either a current or voltage received as an input signal. However, these are merely examples of an amplifier and embodiments of the present invention are not limited in these respects.

A “transimpedance amplifier” (TIA) as referred to herein relates to a device to convert an input current to an output voltage. For example, a TIA may convert an input current received from a photodiode to an output voltage that is substantially proportional

to a magnitude of the input current. However, this is merely an example of a TIA and embodiments of the present invention are not limited in these respects.

A “single-ended terminal” as referred to herein relates to an electrical terminal to transmit or receive a single-ended signal. For example, single-ended terminal may
5 receive a signal as an input signal. However, this is merely an example of a single-ended terminal and embodiments of the present invention are not limited in this respect.

“Differential terminals” as referred to herein relates to a pair of electrical terminals that may receive or transmit a differential signal. For example, differential terminals signal may express a signal as a voltage difference between the terminals.
10 However, this is merely an example of differential terminals and embodiments of the present invention are not limited in this respect.

A “DC signal component” as referred to herein relates to a signal component in an electrical signal that is substantially constant over a time period. For example, such a DC signal component may be characterized as being a “DC voltage component” having a
15 constant voltage over the time period or as being a “DC current component” having a constant DC current over the time period. However, these are merely examples of a DC signal component and embodiments of the present invention are not limited in these respects.

An “AC signal component” as referred to herein relates to a signal component in
20 an electrical signal that fluctuates over a time period. For example, such an AC signal component may be characterized as being an “AC voltage component” having a voltage that fluctuates over the time period or as being an “AC current component” having a current that fluctuates over the time period. However, these are merely examples of an

AC signal component and embodiments of the present invention are not limited in these respects.

A “composite signal” as referred to herein relates to a signal that may be characterized as having a plurality of signal components combined together. For example, a composite signal may comprise a DC signal component added to an AC signal component. However, this is merely an example of a composite signal and embodiments of the present invention are not limited in this respect.

“DC signal removal circuit” as referred to herein relates to a circuit to substantially remove all or a portion of a DC signal component from a composite signal.

For example, a DC signal removal circuit may substantially remove all or a portion of a DC signal component from a composite signal having a DC signal component and an AC signal component, resulting in an isolated AC signal component. However, this is merely an example of a DC signal removal circuit and embodiments of the present invention are not limited in this respect.

A “circuit bonding pad” as referred to herein relates to an electrical contact on a package of an electrical device that enables one or more circuit elements of the device to be coupled to another device or circuit element external to the device package. For example, a circuit bonding pad may be coupled to a printed circuit board by, for example, solder bonding or a device socket. However, this is merely an example of a circuit bonding pad and embodiments of the present invention are not limited in this respect.

An “off-chip capacitor” as referred to herein relates to a capacitor that is external to an electronic device package and is coupled to one or more circuit elements in the electronic device. For example, an off-chip capacitor may be coupled to one or more

circuit elements of an electronic device through a circuit bonding pad. However, this is merely an example of an off-chip capacitor and embodiments of the present invention are not limited in this respect.

A “conductor” as referred to herein relates to a circuit element that transmits a
5 current between physical locations in a circuit. For example, a conductor may couple circuit elements in an electronic device at a circuit node. A conductor may be formed from any one of several conductive materials such as conductive metals (for example, copper, gold or aluminum). However, these are merely an example of a conductor and embodiments of the present invention are not limited in these respects.

10 A “impedance” as referred to herein relates to a property of a circuit element coupled between two physical locations in a circuit that impedes electrical current flowing between the two physical locations. If the current flowing between the two physical locations is an AC current, in one example, an impedance between two physical locations may vary based upon the frequency of the AC current. However, this is merely
15 an example of an impedance and embodiments of the present invention are not limited in these respects.

A “frequency response” as referred to herein relates to a property of a system to provide an output signal in response to an input signal. For example, for a system that receives an input signal having an AC component, a frequency response may determine
20 an output signal having a response that is based, at least in part, on the frequency of the AC component. However, this is merely an example of a frequency response and embodiments of the present invention are not limited in these respects.

A “filter” as referred to herein relates to a portion of a circuit that substantially rejects all or portion of an input signal in a predetermined operating spectrum. In response to an input signal having a wide power spectral density, for example, a filter may remove or substantially a portion of the input signal above a predetermined cut-off frequency. However, this is merely an example of a filter and embodiments of the present invention are not limited in this respect.

Briefly, an embodiment of the present invention relates to filter to provide a filtered voltage signal in response to an amplified voltage signal at an output terminal of an amplifier. The filter may comprise an off-chip capacitor comprising a terminal coupled to a circuit bonding pad and a plurality of conductors formed between the circuit bonding pad and the output terminal. The conductors may be insulated from one another over at least a portion between the output terminal and the circuit bonding pad. However, this is merely an example embodiment and other embodiments of the present invention are not limited in this respect.

Figure 1 shows a schematic diagram of a system to transmit in and receive data from an optical transmission medium according to an embodiment of the present invention. An optical transceiver 102 may transmit or receive optical signals 110 or 112 in an optical transmission medium such as fiber optic cabling. The optical transceiver 102 may modulate the transmitted signal 110 or demodulate the received signal 112 according to any optical data transmission format such as, for example, wave division multiplexing wavelength division multiplexing (WDM) or multi-amplitude signaling (MAS). For example, a transmitter portion (not shown) of the optical transceiver 102

may employ WDM for transmitting multiple “lanes” of data in the optical transmission medium.

A physical medium dependent (PMD) section 104 may provide circuitry, such as a TIA (not shown) and/or limiting amplifier (LIA) (not shown), to receive and condition
5 an electrical signal from the optical transceiver 102 in response to the received optical signal 112. The PMD section 104 may also provide to a laser device (not shown) in the optical transceiver 102 power from a laser driver circuit (not shown) for transmitting an optical signal. A physical medium attachment (PMA) section 106 may include clock and data recovery circuitry (not shown) and de-multiplexing circuitry (not shown) to recover
10 data from a conditioned signal received from the PMD section 104. The PMA section 106 may also comprise multiplexing circuitry (not shown) for transmitting data to the PMD section 104 in data lanes, and a serializer/deserializer (Serdes) for serializing a parallel data signal from a layer 2 section 108 and providing a parallel data signal to the layer 2 section 108 based upon a serial data signal provided by the clock and data
15 recovery circuitry.

According to an embodiment, the layer 2 section 108 may comprise a media access control (MAC) device coupled to the PMA section 106 at a media independent interface (MII) as defined IEEE Std.802.3ae-2002, clause 46. In other embodiments, the layer 2 section 108 may comprise forward error correction logic and a framer to transmit
20 and receive data according to a version of the Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) standard published by the International Telecommunications Union (ITU). However, these are merely examples of layer 2 devices that may provide a parallel data signal for transmission on an optical

transmission medium, and embodiments of the present invention are not limited in these respects.

The layer 2 section 108 may also be coupled to any of several input/output (I/O) systems (not shown) for communication with other devices on a processing platform.

5 Such an I/O system may include, for example, a multiplexed data bus coupled to a processing system or a multi-port switch fabric. The layer 2 section 108 may also be coupled to a multi-port switch fabric through a packet classification device. However, these are merely examples of an I/O system which may be coupled to a layer 2 device and embodiments of the present invention are not limited in these respects.

10 The layer 2 device 108 may also be coupled to the PMA section 106 by a backplane interface (not shown) over a printed circuit board. Such a backplane interface may comprise devices providing a 10 Gigabit Ethernet Attachment Unit Interface (XAUI) as provided in IEEE Std. 802.3ae-2002, clause 47. In other embodiments, such a backplane interface may comprise any one of several versions of the System Packet
15 Interface (SPI) as defined by the Optical Internetworking Forum (OIF). However, these are merely examples of a backplane interface to couple a layer 2 device to a PMA section and embodiments of the present invention are not limited in these respects.

Figure 2 shows a schematic diagram of a system 200 to transmit data in and receive data from an optical transmission medium according to an embodiment of the
20 system shown in Figure 2. An optical transceiver 202 comprises a laser device 208 to transmit an optical signal 210 in an optical transmission medium and a photo detector section 214 to receive an optical signal 212 from the optical transmission medium. The photo detector section 214 may comprise one or more photodiodes (not shown) for

converting the received optical signal 212 to one or more electrical signals to be provided to a transimpedance amplifier/limiting amplifier (TIA/LIA) circuit 220. A laser driver circuit 222 may modulate a modulation current 216 in response to a data signal from a PMA section 232. A laser device 208 may then modulate and power the transmitted
5 optical signal 210 in response to the modulation current 216.

According to an embodiment, the photo detector section 214 may provide a composite signal to the TIA/LIA circuit 220 comprising AC and DC signal components. For example, an input signal received at a TIA portion may comprise an AC current component and a DC current component while an input received at a LIA portion may
10 comprise an AC voltage component and a DC voltage component. Figure 3A shows system 300 to remove all or a portion of a DC signal component of an input according to an embodiment of either the TIA or LIA portion of the TIA/LIA circuit 220. An input signal $s(t)$ comprises AC and DC signal components and a gain section 302 may provide a differential output signal at output terminals 304 in response to the input signal $s(t)$.

15 According to an embodiment, an amplifier 306 receives a voltage signal which is representative of the AC and DC signal components of the input signal $s(t)$. A low pass filter (LPF) 308 may receive the output of the amplifier 306 as an amplification of this voltage signal by a predetermined gain. The output of the LPF 308 may substantially remove an AC portion of the amplified voltage signal to provide a voltage signal that is
20 substantially representative of a magnitude of the DC signal component of the input signal $s(t)$. In response to this filtered output of the LPF 308, a DC signal removal section 310 may remove substantially a portion or all of the DC signal component of the

input signal $s(t)$ so that the gain section 302 receives an isolated AC signal component of the input signal $s(t)$.

According to an embodiment, the gain section 302, amplifier 306 and DC signal removal section 310 may be formed in a single semiconductor device. The LPF 308 may
5 be formed from an off-chip capacitor 314 coupled to the output terminal of the amplifier 306 by a circuit bonding pad 712 and a conductive portion 320. At certain high operating frequencies (e.g., 15 to 20 GHz and higher), the conductive portion 320 may comprise a parasitic resistance 318 and parasitic inductance 316 that may affect the frequency response of the LPF 308.

10 Figure 3B shows a semiconductor layout 322 according to an embodiment of the conductive portion 320 shown in Figure 3A. A plurality of conductors 328 (e.g., copper) may be formed in a semiconductor substrate using techniques known to those of ordinary skill in the art of semiconductor device manufacturing. A first endpoint 324 may be coupled to the output terminal of the amplifier 306 and a second endpoint 326 may be
15 coupled to the circuit bonding pad 312. The conductors 328 may be insulated from one another over at least a portion 332 between the first and second endpoints 324 and 326 by spacings 330.

According to an embodiment, the resistance R of the conductive portion 320 (i.e., between endpoints 324 and 326) may be determined as $R = (\sum 1/R_i)^{-1}$ where R_i is the
20 resistance of an individual conductor 328. The resistance R_i of a conductor 328 may be determined based upon the conductivity of the material forming the conductor 328, the length between the first and second endpoints 324 and 326 and the cross-sectional area of

the conductor 328 (i.e., with respect to the flow of current between the endpoints 324 and 326). The inductance L of the conductive portion 320 may be determined as follows:

$$L = (\sum 1/L_i)^{-1}$$

$$L_i = L_{si} - L_{mi}$$

5 where:

L_i = inductance of a conductor i ;

L_{si} = self-inductance of conductor i ; and

L_{mi} = mutual inductance caused by conductors other than the inductor i and affecting the inductance of the conductor i .

10 The self-inductance L_{si} of a conductor 328 may be determined using techniques known to those of ordinary skill in the art based upon the length, cross-sectional geometries and conductive permeability of the material used to form the conductor 328. Since the conductors 328 are insulated by spacings 330, for each conductor 328 the inductance L_i is reduced from L_{si} by an amount L_{mi} (caused by a field induced by current
15 flowing between endpoints 324 and 326 in one or more of the other conductors 328). This may lower the inductance L contributing to the parasitic impedance over using a single solid conductor. By increasing the number of conductors 328, the parasitic resistance and parasitic inductance of the conductive portion 320 may be lowered. Accordingly, increasing the number of conductors 328 may lower the parasitic impedance in the
20 conductive portion 320 by lowering the parasitic inductance and parasitic resistance.

Figure 3C shows a schematic diagram of an amplifier 340 according to an embodiment of the amplifier 306 shown in Figure 3A. The amplifier 340 may comprise a first amplification stage 342 having a gain A_1 followed by a second amplification stage

344 having a gain A_2 . The first amplification stage 342 may receive a differential input signal (e.g., from output terminals 304) through resistors 350 and 352 having a resistance R_2 . The second amplification stage 344 may receive power from a voltage source through resistor 348 having a resistance R_1 . An off-chip capacitor 314, coupled to an output of the second amplification stage 344 by conductive portion 320, may have a capacitance of C_{off} . A first pole in the frequency response of the LPF 308 may create a cut-off frequency determined by the quantity $R_1 C_{off}$. A second pole in the frequency response of the LPF 308 may be determined by the quantity $A_1 A_2 C_2 R_2$. A parasitic impedance resulting from the parasitic inductance 316 and parasitic resistance 318 may cause a zero in the frequency response of the LPF. According to an embodiment, by selecting the values A_1, A_2, C_2, R_2 , the second pole may be positioned in the frequency response of the LPF 308 to at least partially cancel the zero caused by the parasitic impedance.

In addition to removing the AC portion of the amplified voltage signal, the LPF 308 may remove the noise added to the voltage signal to enhance the accuracy of the output voltage signal in representing the magnitude of the DC signal component of the input signal $s(t)$. This may enable system designers to use noisier, less costly design for the amplifier 306 as the LPF 308 may remove noise added to the input signal. This may also enable designers to build a system with an enhanced sensitivity to optical signals received from the photo detector 214.

As discussed with reference to Figures 4A through 6, the system 300 may be implemented in either a TIA portion or LIA portion of the PMD 204 according to alternative embodiments of the present invention. However, it should be understood that

the embodiments of the present invention in these implementations are merely example implementations, and that other embodiments may be implemented in other feedback systems that receive a composite input signal comprising DC and AC signal components.

Figures 4A and 4B show a schematic diagram of alternative embodiments of a TIA 400 according to an embodiment of the PMD section 204 shown in Figure 2 incorporating a system to remove substantially all or a portion of a DC current component of an input signal according to an embodiment of the system 300 shown in Figure 3. An amplifier 402 may receive a single-ended input 404 from a photodiode 406 that is responsive to an optical data signal and provides a differential output at output terminals 412 and 414. The TIA 400 may be formed as part of an integrated device (e.g., as part of a single device including the TIA 400 and other portions of the PMD section) in a semiconductor process such as a complementary metal oxide semiconductor (CMOS) manufacturing process. However, this is merely an example of a process that may be used to form a TIA and embodiments of the present invention are not limited in this respect.

Figure 5 shows a schematic diagram of an amplifier 502 according to an embodiment of the amplifier 402 shown in either Figures 4A or 4B. A first amplification stage comprises a transistor 506. A gate of the transistor 506 may receive a single ended input signal on a single-ended input terminal 404 from the photodiode 406. In response to the input signal, a second amplification stage comprising a differential amplifier formed by transistors 508 and 510 may provide an output voltage on differential output terminals 512 and 514. However, this is merely an example of a multi-stage amplifier

that may be implemented in a TIA and embodiments of the present invention are not limited in this respect.

According to an embodiment, the input signal 404 comprises an AC current component and a DC current component. In the embodiment of Figure 4A, an amplifier
5 416 may comprise input terminals to receive a voltage from output terminals 412 and 414 which is representative of the magnitude of the composite AC and DC current components of the input signal 404. In the illustrated embodiment, the voltage from the output terminals 412 and 414 may have a magnitude that is substantially proportional to a magnitude of the composite AC and DC current component. An LPF 418 receives an
10 output of the amplifier 416 comprising an amplification of the voltage from the output terminals 412 and 414. According to an embodiment, the LPF 418 may substantially remove a portion of the amplified voltage which is representative of the AC current component to isolate the portion of the amplified voltage which is representative of the DC current component. The LPF 418 may also remove portions of noise added by the
15 amplifier 416 in providing the amplified voltage. The output of the LPF 418 (comprising the isolated portion of the amplified voltage which is representative of the DC current component) may be provided to a sink transistor 420 to substantially remove all or a portion of the DC current component from the input signal 404.

In an alternative embodiment to detecting the composite signal from the output
20 terminals 412 and 414, Figure 4B shows that the amplifier 416 may provide a voltage representative of the composite signal from across a feedback resistor 408 as shown in Figure 4B. The output terminal 412 provides feedback signal to the single-ended signal 404 through a resistor 408. An input voltage V_{in} at the single-ended input 304 may be

substantially proportional to an output voltage V_{out} at an output terminal 412. The voltage across the resistor 408 may be substantially proportional to the magnitude of the current provided at the single-ended input 404. As such, the voltage across the resistor 408 may have a DC voltage component and an AC voltage component that are

5 substantially proportional to the magnitudes of respective DC and AC current components of the input signal received at the single ended input 304. As discussed above with reference to the embodiment illustrated in Figure 4A, the amplifier 416 may provide an amplified voltage signal to the LPF 418. In response, the LPF 418 may generate a voltage which is representative of an isolated DC current component of the

10 input signal 404. The sink transistor 420 may then remove substantially all or a portion of the DC current component of the input signal 404 in response to voltage representative of the isolated DC current component received at the gate terminal.

The LPF 418 comprises an off-chip capacitor 434 coupled to an output terminal of the amplifier 416 by a conductive portion 440 and a circuit bonding pad 432. At a

15 particular operating frequency, the conductive portion 440 may comprise a parasitic resistance 438 and parasitic inductance 436. As discussed with reference to Figures 3A through 3C, the conductive portion 440 may comprise a plurality of conductors such that the parasitic impedance (resulting from the parasitic resistance 438 and parasitic inductance 436) may be reduced over a conductive portion comprising a single solid

20 conductor.

By performing low pass filtering after the amplification at amplifier 416, much of the noise added by the amplifier 416 may be removed by the LPF 418. Accordingly, this may enable system designers to use noisier, less costly design for the amplifier 416 as the

LPF 418 may remove noise added to the input signal. Additionally, low pass filtering at the output of LPF 418 may enable the use of a noisier, higher gain design for amplifier 416 to drive the sink transistor 420 for removing substantially all or a portion of a DC current component from the single-ended input terminal 404.

5 Figure 6 shows a LIA 600 according to an embodiment of the TIA/LIA section 220 of the PMD 204 shown in Figure 2. The LIA 600 may be formed as part of an integrated device (e.g., as part of a single device including the LIA 600 and other portions of the PMD section) in a semiconductor process such as a complementary metal oxide semiconductor (CMOS) manufacturing process. However, this is merely an example of a
10 process that may be used to form a LIA and embodiments of the present invention are not limited in this respect.

 A TIA (not shown) may provide a differential voltage as an input signal 604. In response to the input signal 604, an amplifier 602 may provide a differential output voltage at output terminals 612 and 614. According to an embodiment, the input signal
15 604 may be a composite signal comprising an AC voltage component and a DC voltage component. A clamping circuit 620 may remove substantially all or a portion of the DC voltage component from the input signal 604.

 An amplifier 616 may receive the differential output voltage at as inputs to provide an amplified voltage signal comprising an AC voltage component and a DC
20 voltage component as an output. An LPF 618 may remove substantially all of the AC voltage component from the amplified voltage signal to provide an isolated DC voltage component to the clamping circuit 620. In response to the isolated DC voltage

component, the clamping circuit 620 may remove substantially all or a portion of the DC voltage component of the input signal 604.

The LPF 618 comprises an off-chip capacitor 634 coupled to an output terminal of the amplifier 616 by a conductive portion 640 and a circuit bonding pad 632. At a particular operating frequency, the conductive portion 640 may comprise a parasitic resistance 638 and parasitic inductance 636. As discussed with reference to Figures 3A through 3C, the conductive portion 640 may comprise a plurality of conductors such that the parasitic impedance (resulting from the parasitic resistance 638 and parasitic inductance 636) may be reduced over a conductive portion comprising a single solid conductor.

While there has been illustrated and described what are presently considered to be example embodiments of the present invention, it will be understood by those skilled in the art that various other modifications may be made, and equivalents may be substituted, without departing from the true scope of the invention. Additionally, many modifications may be made to adapt a particular situation to the teachings of the present invention without departing from the central inventive concept described herein. Therefore, it is intended that the present invention not be limited to the particular embodiments disclosed, but that the invention include all embodiments falling within the scope of the appended claims.